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ABSTRACT

Science education seems to have become fashionable again, and with it the recurrent theme of scientific literacy for the masses. Some 25 years ago it was mainly the launching of Sputnik that triggered a curriculum reform movement in science and mathematics. Today, the impetus for reform and the achievement of scientific literacy appears related to such issues as the number and quality of scientists, engineers, and technicians; the technical illiteracy of most high school and college graduates; a growing shortage of qualified high school science teachers; and declining test scores in science. However, an examination of these and other issues suggests that scientific literacy may be difficult to achieve due to the lack of a real incentive for the average citizen to become literate in science and the lack of methodology in teaching science to non-science students in meaningful, yet painless ways. What is needed to address problems posed under the guise of a "crisis in science education" is to move toward a more realistic goal: technological literacy. One reason for fostering this goal is that unlike scientific literacy, technological literacy focuses on social, cultural, and economic changes brought on by technology, changes which touch more closely the lives of most people. (JN)

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SCIENTIFIC LITERACY: REALITY OR ILLUSION?

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Precollege science education in the United States began in a small way around the turn of the century when the secondary school movement finally took shape and then grew rapidly. Science education was hardly viewed then as a means to mass literacy in science. First, only about 5 percent of the eligible population attended secondary school, compared to nearly 100 percent today. Second, the science that was taught was mainly nature study in the elementary grades and natural history and practical science in the secondary schools. What little basic science was taught was simply an extension of college-level science instruction -- a complaint that one often hears expressed today.

Thus in the beginning science instruction was rationalized solely as a mental discipline or cultural imperative -- not as a means to an enlightened citizenry. It wasn't until the second half of the century that science education began having social overtones. Technology had by then influenced our lives more profoundly than ever before. We had become more industrialized and concerned over our environment. And, perhaps most importantly, Sputnik created an urgency that could be capitalized upon by both the scientific and the science education communities, which they did.

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so what previously had been mainly a cultural force now became a social imperative: the American public was told that in order to deal effectively with the expanding technology, and particularly with those social issues having a scientific base, it would have to attain a level of scientific understanding, or literacy, as we generally call it, that the U.S. never before had.

In the past quarter century we have come full cycle on one massive attempt to develop such scientific literacy -- a kind of literacy, by the way, on which there is no common agreement as to definition. We've had both feast and famine during this period in terms of support for science education -- both public and governmental, and we are presently in the midst of what many are calling a "crisis" in science education brought on by a marked decrease in such support in recent years.

One supposes that all scientists -- and science educators -- hope for the Utopian world in which everyone is fully literate in science and all societal problems having a scientific base are solved logically rather than emotionally. But we are so very far from such a society that at least in the United States one can properly challenge the basic premise that so-called "scientific literacy" is achievable -- or is even worth the effort.

The United States is currently reassessing its educational priorities, particularly in science. Science education seems to have become fashionable again, and with it the recurrent theme of scientific literacy for the masses. To briefly review the background, it all began in late 1980 with a science policy report commissioned earlier that year by President Carter (1). In that report the Director of the National Science Foundation and the Secretary of Education addressed two basic issues: first, the number and

quality of professional scientists, engineers and technicians being turned out by our universities and technical schools, and second, the technical illiteracy of most of today's high school and college graduates in the U.S. The report focused attention on science education generally and attracted a great deal of media notice by its inevitable comparison between science education in the U.S. and in the Soviet Union.

Many saw the report as a rallying cry that would somehow trigger increased government support for science education, a hope that was quickly dashed by the incoming Reagan administration as it proceeded to dismantle the NSF Directorate for Science Education and the Department of Education. What previously had been a matter of concern mainly to the science education community quickly escalated into a national "crisis", with as much grist for the political mill as for concerned educators. Neither of these agencies has disappeared, by the way, largely because of the political clamour that resulted.

Other commission reports soon took up the chorus: The National Science Board Commission on Precollege Education in Mathematics, Science and Technology, in its initial report, "Today's Problems, Tomorrow's Crises", concluded that the principal concern was a steady decline in student achievement (and participation) in science and mathematics, coming at a time of increasing national need (2). The report also urged increased scientific literacy of all citizens for . . . 'full participation in the society of the future'. Less provincial is a more recent report, by the National Commission on Excellence in Education, which deplored the nation's overall mediocre performance in precollege education, not only in science but in all disciplines, and called for major reforms across the board (3).

The persistent tone of these reports, together with the political overtones they have generated, are bound to provoke substantial changes over the next few years in the style and content of the total educational structure in the U.S. including science and mathematics. They prompted Fred Hechinger, Education Columnist for the New York Times, to remark: "The problems of science education couldn't be solved by throwing money at them. Can they be solved by throwing commission reports at them?" One must applaud any genuine movement to improve precollege education generally, and the scientific community particularly will undoubtedly cheer all efforts designed to stimulate greater interest in science education. But there is a danger here that in our rush to correct the perceived deficiencies in science education we may not only repeat the mistakes made during the previous "crisis", we may also create new ones.

Some 25 years ago it was mainly the launching of Sputnik that triggered a huge, multi-billion dollar curriculum reform movement in science and mathematics, one that remains unparalleled in the entire history of the U.S. educational movement. The program had two major objectives. One was to stimulate greater interest in science among precollege students in the hope of alleviating the scientific manpower shortage that then existed. The other was to make science teaching more effective in order to increase the general level of scientific literacy. Whether the result of this massive educational enterprise, or, more likely, because of the post-war "baby boom" coupled with a great market demand for trained scientists and engineers, the first objective was pretty much satisfied in the two succeeding decades. The second objective turned into a dismal failure, and the likelihood is that unless this goal is sharply modified, any new attempts to attain it are also doomed to fail.

What exactly is the current "crisis" in science education in the United States? Declining test scores in science are given as one indicator that we have reached a critical stage. A growing shortage of qualified high school science teachers is cited as another. Both are true, of course, but in practical terms what are likely to be the consequences of these? The usual response includes: (a) an impending shortage of trained scientists and engineers, and (b) continued scientific illiteracy of our citizens generally, including most of the nation's leaders and decision-makers. The first is debatable; the second would be the case irrespective of a crisis. To assert that we currently have a major shortage of scientists and engineers, or that such a shortage is imminent, is a gross exaggeration. Spot shortages exist in a few engineering fields, but in most, supply and demand are in balance, and there are actual surpluses in a number of science and engineering disciplines (4). In fact, the National Science Foundation reported recently that a nine-year decline in the U.S. production of doctorates in science and engineering ended in 1981. Schools in the U.S. operate under a sensitive feedback system that somehow manages to keep students informed of the current manpower situation in all technical fields, such that the supply shifts to meet the demand -- with some time lag, of course.

This is an important point that appears to have been ignored in the current "crisis". What many fail to realize is that in the final analysis, the supply of technically-trained individuals in our society is limited not by our educational system -- but by the marketplace, and the same is true in most highly industrialized societies -- at least in the free world. The point deserves more than a little emphasis. We cannot ever expect the ideal situation in which the supply exactly equals the demand. Nor can we expect the luxury of stockpiling surplus scientists and

engineers in some gainful manner. So how do we manage to supply the changing needs of our industrial economy for such talents? Mostly by "muddling through" in much the same way that we resolve teacher shortages in the sciences -- through "occupational mobility".

Several weeks ago there was a symposium at the National Academy of Sciences entitled "Labor Market Conditions for Engineers: Is There a Shortage?" The conclusion of experts present was, in effect, that a shortage is often in the eye of the beholder.

Approximately 1.2 million individuals are currently counted as engineers in the American work force. It is generally agreed that the growth rate in demand will average 5% per year over the next 10 years, which means that roughly 500,000 new engineering jobs will open up over this period. However, it is estimated that we will have only half enough newly graduated engineeers to fill these jobs. Does this mean a 50% shortfall? Not if the engineering marketplace continues to operate as it has.

A key factor in smoothing out the manpower fluctuations in engineering has been what is commonly called "occupational mobility" -- individuals not classified as engineers or engineering specialists who fill positions with engineering job descriptions. They may have been trained in physics or math, or may be engineers transferring back from other pursuits -- or teachers or even technicians upgraded to fill engineering slots. It is surprising how well in the past employers have managed to balance supply and demand by orchestrating this occupational mobility.

Thus the consensus of the experts is that there is not likely to be a shortage in the sense of jobs going begging. Half the additional jobs, should they develop, would

be filled by newly graduated engineers and the rest through occupational mobility. The question of quality naturally arises in this connection, just as it does is in the case of science teachers working out of license. How much do we as a nation lose by filling engineering shortages in this way -- or science teaching positions with less well-qualified teachers? The answers are not clear. Instinctively, one would think that we must lose something -- but the alternative, having a surplus of engineers, or of science teachers, could be even more debilitating to our society.

Fewer than 10 per cent of precollege students in the U.S. profess to a genuine interest in science, and roughly one-quarter of this group actually goes on to become professional scientists and engineers, of which we currently produce about 200,000 per year. The "attrition", if it can be called that, is probably due more to market saturation than to any other single factor. The present economy couldn't possibly absorb four times, or even twice, this number. Nor could it do so in the foreseeable future. But even if it could, there is no reason to believe that the requisite number of students would not turn to science, or that our precollege education system, however inadequate it may be in certain respects, could not properly prepare these students, bearing in mind that at most we would have to prepare only 10 per cent of our high school students for careers in science. Without going into detail on such expedients as specialized high schools, dual track systems, master teachers, extra-curricular programs for science-bound students, etc., it should be evident that, given the need, there are ways to adequately prepare this number of science-bound students. This could be done, if required, despite a shortage of qualified high-school science teachers, particularly since most high-school science teaching today is devoted to the 90 per cent of students who are not science-bound, nor have a great interest in science. These students

enroll in science courses mainly because they are required to do so, presumably as part of our overall effort to develop a scientifically literate public.

The educational battlefield is littered with the pronouncements of those who have sought to persuade the U.S. public that understanding something about science is the sine qua non of an educated person. To date, all efforts to develop such literacy have failed, including the massive effort that followed Sputnik, and there is no reason to believe that new attempts to achieve widespread public literacy in science will be any more successful. Two reasons for this stand out above others: First, the public remains unconvinced that the effort it must expend to gain a reasonable understanding of science is actually worth the prize. Clearly, the average educated adult in the United States manages quite well in our society with little or no understanding of science, or for that matter, of mathematics beyond simple arithmetic. Knowledge of these disciplines is not perceived by the public as being essential to either the "good life" or to a successful career outside of science. Nor is there any stigma attached to being ignorant of science. Some intellectuals, in fact, display such ignorance almost as a "badge of honor". Thus, there is no real incentive for the average U.S. citizen to become literate in science, either for economic reasons or because of peer pressure.

As an undergraduate I recall a professor of mathematics at Columbia, who happened also to be a dean, who was fond of saying that all the mathematics that the average person really needs could be written on the inside of a matchbook cover. The remark always disturbed me because reality had not yet warped my idealism. But now I realize that he was right, and what's more, much the same is true of science.

The other reason why scientific literacy is so difficult to achieve is that we have not learned how to teach science to the non-science student in a meaningful, yet painless fashion. For the most part, the kind of science we teach appeals to the professional scientist and to science - bound students, but does not make a lasting impression on the average student. This is understandable, since most of the basic concepts of science do not accord with our everyday common sense experiences. Students are asked to accept on faith the seemingly bizarre models and explanations that constitute the foundations of modern science. And to make matters worse, the native language of science, mathematics, is also foreign to most students. There are no common sense counterparts for these models, nor are there likely to be any in the future because the ultimate explanations in science are at the molecular and sub-molecular levels, where reasoning by analogy with our everyday experiences requires an enormous stretch of the imagination. In the face of all these obstacles, seeking even a small degree of enduring scientific literacy in our general population becomes a forlorn hope. A large part of the reason, following the theory of economist (and Nobel Laureate) Herbert Simon, may be that individuals can process only so much information, and hence tend to take shortcuts that avoid formal logic.

How, then, should we address the problems posed under the guise of a "crisis in science education"? Suppose we had better high school science teachers, improved laboratory facilities, another round of new curricula, what might be the end result? Probably test scores in science would improve, at least for non-science-bound students, but we know from past experience that this is no valid indicator of future scientific literacy. Such changes probably would provide the science-bound student with a more fulfilling educational experience, but as we have seen, they would not result in

more scientists and engineers unless the market demand for such personnel increased dramatically.

The one positive result that hopefully will emerge from the present "crisis" is a sober reevaluation of our goals in science education. Should we continue trying to achieve the elusive common literacy that for so long has been the implied objective of minimum science requirements in our high schools and colleges? Or should we be more realistic and aim at a target that may be easier to hit -- namely, technological literacy? Before pursuing this thought let me pose another problem that I believe stands in the way of improved literacy in science -- one that may be unique to the United States.

We know that most students do not willingly study science. A major reason, as we have seen, is lack of adequate incentive. True, science can be interesting, exciting and even intellectually stimulating, but it does require a special effort to understand science and hence one must have a good reason for making this effort.

Strangely enough, the chief barrier to improved scientific literacy in the United States may be the ready availability of higher education. As if by some grand design the U.S. is the only nation in the world to provide what amounts to universal higher education. In practice, this means that virtually every high school graduate is assured of admission to a college, although not necessarily one of his or her choosing. The statistics are impressive. While only 75 percent of our students graduate from high school, fully 60 percent of this number go on to college, and half of the latter group complete their degrees. Thus, nearly one-quarter of our school age population eventually go through college. And at each level of this educational ladder practically all students are exposed in some fashion to science.

Most high schools have a formal science requirement for graduation. Where state education departments fail to mandate such a requirement the colleges generally accomplish the same end by requiring science, either formally or informally, for admission. And the colleges, in turn, perpetuate the notion that science should be part of the lore of all educated adults by requiring at least a taste of it for most graduates. With all this exposure to science by such a large segment of the U.S. population one would think that scientific literacy should be the norm rather than the exception, but few students come through this experience with more than a fleeting glimpse of science and fewer still retain any lasting impression of the scientific world.

If the purpose of compulsory science education in our high schools and colleges, beyond training the future scientists and engineers for society's needs, is to produce a scientifically literate public, we have failed badly in the past and we will continue to fail unless society somehow becomes convinced that such literacy is important. Presently, all that is really accomplished by requiring science in high schools and colleges is to preserve the size and variety of our science departments. This may be sufficient reason for having science requirements, for we might otherwise have great difficulty in preparing professional scientists and engineers, but if this is indeed the reason we should face it squarely and stop deluding ourselves (and students) into believing that we are at the same time achieving scientific literacy for all.

Strangely enough, our colleges have it within their collective power to take a giant step toward achieving literacy in science. If, for example, admission requirements by colleges in the United States were to include not merely some high school science credits but a <u>demonstrable</u> measure of scientific literacy, it would both force the high schools

to upgrade their science offerings and provide the necessary incentive for students to take their science requirements more seriously. The colleges could then return to the practice of offering only rigorous courses in science and technology instead of the watered-down versions with catchy titles that have lately come into vogue, but which do little for the cause of scientific literacy.

Knowing that poor achievement in science is no barrier to college admission -- or to earning a college degree -- is hardly an inducement to regard seriously this segment of the curriculum. The situation is far different in the other highly industrialized countries with which it has become fashionable to compare the U.S. educational structure: U.S.S.R., Japan, United Kingdom and West Germany. In these countries fewer students (percentage-wise) enter the equivalent of high school, but of those that do almost all graduate (e.g., 96 percent in Japan). Then, because college enrollments are severely limited, the competition is so keen that demonstrated proficiency in science is taken for granted as a prerequisite and high school students prepare themselves accordingly. It is therefore not surprising to find the educated adults in these countries generally more literate in science and technology than their counterparts in the United States.

Perhaps scientific illiteracy is the price that we in the U.S. must pay for our form of democracy in higher education -- but if so we should not confuse exposure to science with understanding it.

Returning now to the question of technological literacy, if we cannot achieve scientific literacy -- and I believe we cannot in the United States -- perhaps the motivation and incentive for attaining technological literacy are easier to come by. Most students, and the public generally, relate

more easily to technology than to science simply because their daily contact is with the products of technology. Some call it "applied science", others may think of it as "practical science", but whatever name one gives it technology has the advantage over pure science of keeping the student in touch with the "real" world.

A properly designed technology curriculum is not, as one might think, simply a course in "kitchen chemistry" or in the workings of a radio or gasoline engine. It is far more encompassing. The primary objective of such a curriculum should be to make students feel comfortable with their total surround, not to regard the end products of our scientific enterprise with awe or suspicion but to understand enough about them to have a sense of being in control -- to know their capabilities and limitations, and to appreciate their risks -- to know what to expect of the machines that do much of our work for us, what human jobs they can replace in our society and what they cannot be expected to do economically -- and to be aware of the subtle distinction between knowing what can be done and what is beyond reasonable expectation, for when assessing the vistas of technology it is often better to know its limitations than its prospects.

Science, engineering and technology are related but distinct enterprises. In the public mind, however, they are generally lumped together under the broad heading of "science". At least part of the problem of scientific literacy probably can be traced to just this confusion in terms. The overall enterprise generically known as "science" begins in the real world with observation and in the end returns to that world in the form of technology, i.e., in the form of real things. The beginning and end are easy to relate to because they conform to our everyday experiences. We all "observe" nature to some degree and we all have direct

contact with the end products of science -- i.e., with the machines and structures and manufactured products that derive from its technology.

Between the two lies the strange and exciting world of science -- where one seeks to understand the underlying causes of natural phenomena. The problem, however, is that in seeking such understanding we often must resort to abstractions that do not seem to conform with the real world, i.e., with our practical, common-sense perceptions of that world. Stated simply, where science seeks an ultimate understanding of the natural world, and engineering seeks to apply such knowledge to practical needs, technology deals with the tools and techniques -- the methods of producing the end products for a modern industrial society. One does not need to understand the ultimate causes of things to appreciate their end uses.

Nor does it follow on the other hand, that being literate in science and mathematics automatically makes one technologically literate. There are basic concepts that are unique to engineering and technology, rather than being merely applications of science and mathematics. Examples of these include operations analysis, information and knowledge engineering, and feedback control systems, which are now spawning the new robotics industry. And perhaps most important of all, the concept of risk-benefit analysis, which can be so helpful in resolving societal issues.

The development of civilization since the Middle Ages is closely linked with the history of technology -- much more so than with the history of science and mathematics -- for since that period nations have encouraged industrialization by granting exclusive rights or monopolies for the development of innovative products or processes. This led in the Renaissance to the establishment of the first modern

patent system, which ultimately provided much of the incentive for the industrial revolution and the setting for contemporary science. Thus, there is a strong rationale for understanding the role played by technology in the development of modern civilization, and its probable role in the future evolution. Technological literacy encompasses the social, cultural and economic changes brought on by technology -- as well as the technology itself.

The pervasive societal issues that are said to have a scientific base, more often then not are really based on technology. Technological literacy implies that one is at least conversant with the technical bases of such issues as nuclear power, environmental pollution, genetic engineering, computers, robotics and the like -- and hence cannot easily be misled by demagogues or by sensational reporting.

Times are changing. We are moving into a more pronounced technological age, one in which technology promises to touch more closely the lives of most people. The workplace generally will expect from its employees a better understanding of technology than ever before. Thus, where there were few, if any, incentives in the past for one to become literate in science, there may be very compelling reasons in the future for widespread technological literacy.

I have tried to argue against continuing to seek for general scientific literacy. There is no real need for it; nor do I think it attainable. Let us forget the usual platitudes about scientific literacy and move toward a more realistic goal: technological literacy. Otherwise, we should seriously consider eliminating all science requirements for the general student. Forcing students to take science is akin to leading a horse to water. There is no assurance that either one will actually drink.

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